

ON-ORBIT CONSTRAINTS TEST - PERFORMING PRE-FLIGHT TESTS WITH FLIGHT HARDWARE, ASTRONAUTS AND GROUND SUPPORT EQUIPMENT TO ASSURE ON-ORBIT SUCCESS

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ABSTRACT

On-Orbit Constraints Test (OOCT's) refers to mating flight hardware together on the ground before they will be mated on-orbit. The concept seems simple but it can be difficult to perform operations like this on the ground when the flight hardware is being designed to be mated on-orbit in a zero-g and/or vacuum environment of space. Also some of the items are manufactured years apart so how are mating tasks performed on these components if one piece is on-orbit before its mating piece is planned to be built. Both the Internal Vehicular Activity (IVA) and Extra-Vehicular Activity (EVA) OOCT's performed at Kennedy Space Center will be presented in this paper. Details include how OOCT's should mimic on-orbit operational scenarios, a series of photographs will be shown that were taken during OOCT's performed on International Space Station (ISS) flight elements, lessons learned as a result of the OOCT's will be presented and the paper will conclude with possible applications to Moon and Mars Surface operations planned for the Constellation Program.

KEYWORDS: On-Orbit Constraints Test (OOCT), Fit checks, Test Aids, Flight Hardware, Ground Support Equipment, Internal Vehicular Activity (IVA), Extra-Vehicular Activity, Element (EVA).

INTRODUCTION

The Space Station Hardware Integration Office (SSHIO) was formed at Kennedy Space Center (KSC) to create an organization of personnel with flight hardware processing experience that would then go out into the field to provide assistance with the design and building of International Space Station (ISS) Elements. As part of the responsibilities SSHIO personnel were given existing ISS problems to solve or concerns to alleviate. One big concern of the Astronauts dealt with ISS EVA & IVA hardware integration on-orbit, "Astronaut - How do we verify hardware built and launched on different missions will connect together in orbit?".

The On-Orbit Constraints Test (OOCT) concept was developed to alleviate the concern by combining Flight Hardware, flight hardware simulators called "Test Aids", Astronaut and ground processing personnel in a series of pre-launch tests performed during KSC ground processing on ISS Flight Hardware. Performing "Dry-runs" of the on-orbit EVA & IVA hardware/operations before launch, OOCT's included connecting cables, fluid umbilical & ducts that would test mating/demating, clocking, routing, etc. OOCT performed by Astronauts/rep with Mission personnel supporting, using Boeing Houston Procedure/Task leader with KSC NASA signature authority. OOCT is a physical check of interfaces, not a functional check.

FIT CHECK & OOC T CONCEPT

The idea was very simple, fit check, which meant a physical mating/connection of flight hardware, the actual flight hardware together before being launched into space. Then for those flight items that have already been launched or could not be mating together while on the ground, create high fidelity simulators (called Test Aids) so any future/existing flight hardware would then have an OOC T performed to try and assure the both flight hardware pieces (the half already in space, its mating half still on the ground) would connect on orbit. One question that always came up was, "What does the OOC T verify that can't be verified by the fit check?" Below describes what is verified during both operations, followed by Figure 1 – ISS fit check and OOC T concept:

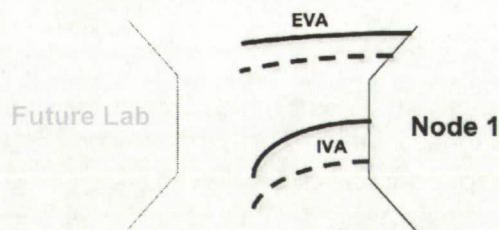
Fit Check verifies:

- Flight-to-flight mate
- Connector Clocking
- Connector to connector interference
- Connector to adjacent hardware
- Tool access
- Hand access
- Mating order of installation

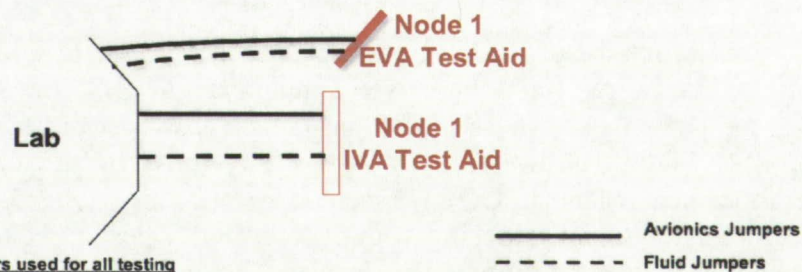
Additional data obtained from OOC T:

- Line length check
- Cable clocking
- Routing obstructions

"Today" - Fit check future Lab flight jumpers to Node 1 flight Element



"X time in the future" - OOC T of Lab flight jumpers to Node 1 test aid (by default you get fit check to Lab, piggyback on testing so only connect to flight hardware one time)



Note: Same flight jumpers used for all testing

Figure 1 – ISS fit check and OOC T concept

WHAT IS REQUIRED TO PERFORM SUCCESSFUL FIT CHECKS AND OOC's

The on-orbit configuration(s) of the flight hardware is required to begin the OOC process. There could be multiple on-orbit configurations, as was the case for the ISS Z1 Truss. An early on-orbit configuration has its deployable tray stowed when Z1 to Node 1 flight connections are performed during the ISS 3A Mission. The same tray is then deployed to allow connections of Z1 Truss to the Laboratory Module during the ISS 5A mission that occurred over a year after the 3A mission. So the OOC on Z1 Truss would be tested in two configurations that are described in more detail later in this paper, but a graphic on-orbit representation is shown in Figure 2 – ISS 3A Mission and 5A Mission on-orbit configurations.

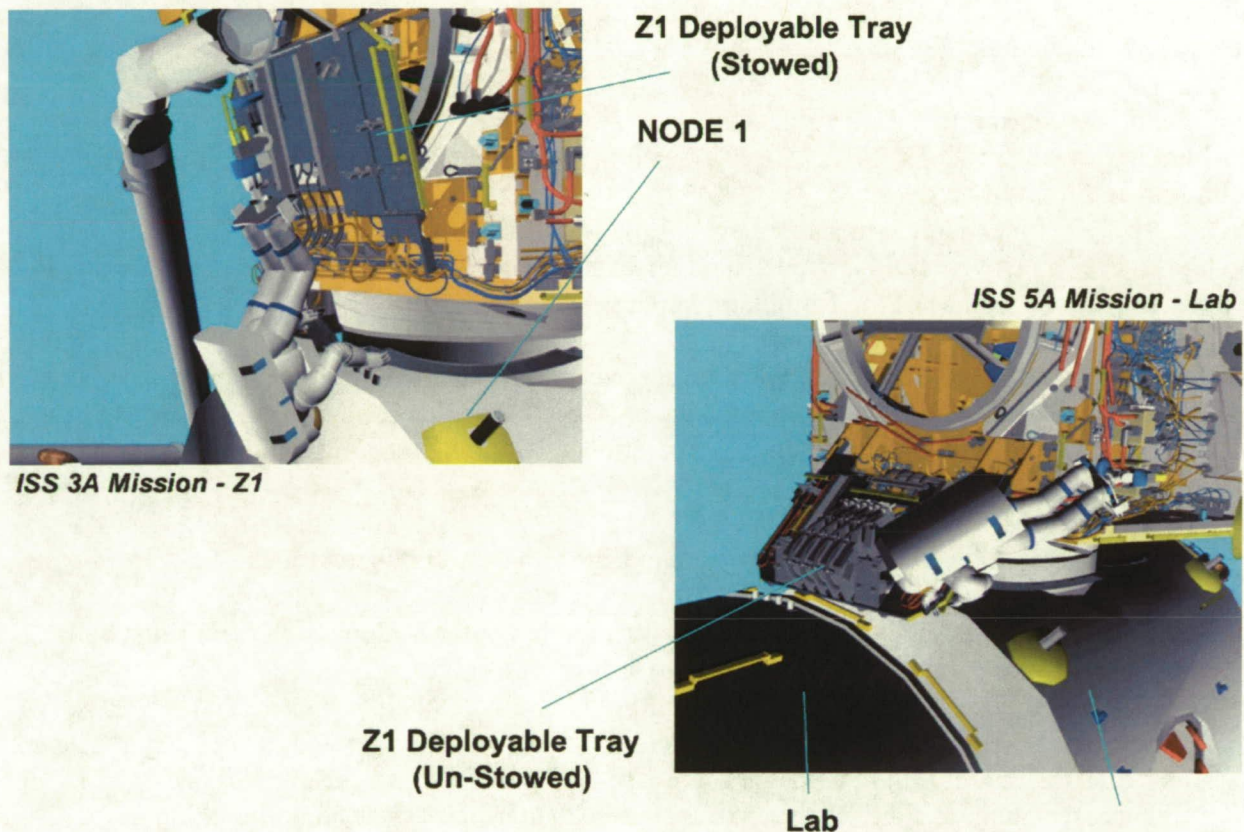


Figure 2 - ISS 3A Mission and 5A Mission on-orbit configurations.

Once the on-orbit configuration was determined, the next step is, could the mated items be connected on the ground before launch. If the ground processing schedules overlapped and both items were at the Kennedy Space Center at the same time, then a flight-to-flight check could be done. Many ISS Elements were at KSC at the same time, unfortunately the design of the ground support equipment, containing the flight hardware, would not allow ISS Elements to physically mate together on the ground.

Another problem was the interfacing cable and fluid lines (sometimes called jumpers) that routed between the Elements would not be ready for both elements. The jumpers used for a future element were still being fabricated when the current element was launched. Because of these problems, the fit check would be performed first followed by the OOCCT as shown in Figure 1.

There being no means to physically mate both flight hardware elements together, a Test Aid would have to be designed and built to substitute for one of the flight elements. This mostly was done for the element that would be launched first. The idea here is that first element, once on-orbit, can't really be modified (i.e. a "fixed" configuration), so a test aid would simulate the on-orbit element in the event any problems discovered during the OOCCT, would be fixed on the future flight element (and/or the jumpers) still on the ground. The trick was how to get a high fidelity Test Aid built of the first element before it is launched. A number of techniques were used that included;

- Flight hardware Interface Control Documents
- Flight hardware drawings
- Photos of the flight hardware
- Direct physical mechanical measurements of the flight hardware and
- Digital Pre-Assembly (DPA) (electronic measurement of flight hardware to generate high accuracy digital model) of the flight hardware

Two different types of Test Aids were built, one to simulate EVA connections the second to simulate the ISS Common Berthing Mechanism (CBM) for IVA connections, shown in Figure 3 - IVA Test Aid. Many other design & operational features were built into the Test Aid that included:

- Build IVA Test Aid CBM ring narrower than flight ring so it does not touch Flight Hardware
- Build a few rings to save cost
- Build feed through change out panels to allow multiple configurations of the few rings built
- Obtain flight-like connectors/fluid fittings to secure on test aid
- Model other adjacent flight hardware using Flight Hardware compatible foam
- Build test aid stand with high accurate X, Y & Z adjustments to allow high accuracy placement of test aids to simulate flight configuration. Use for both EVA and IVA OOCCT's
- Build access way in test aids to give Astronauts a "hatch-like" view and orientation like they would see on-orbit
- Fabricate and assembly test aids in Florida to allow quick turn-around and repair of test aids, saving transportation cost as well, eliminated transportation to non-Florida location for work

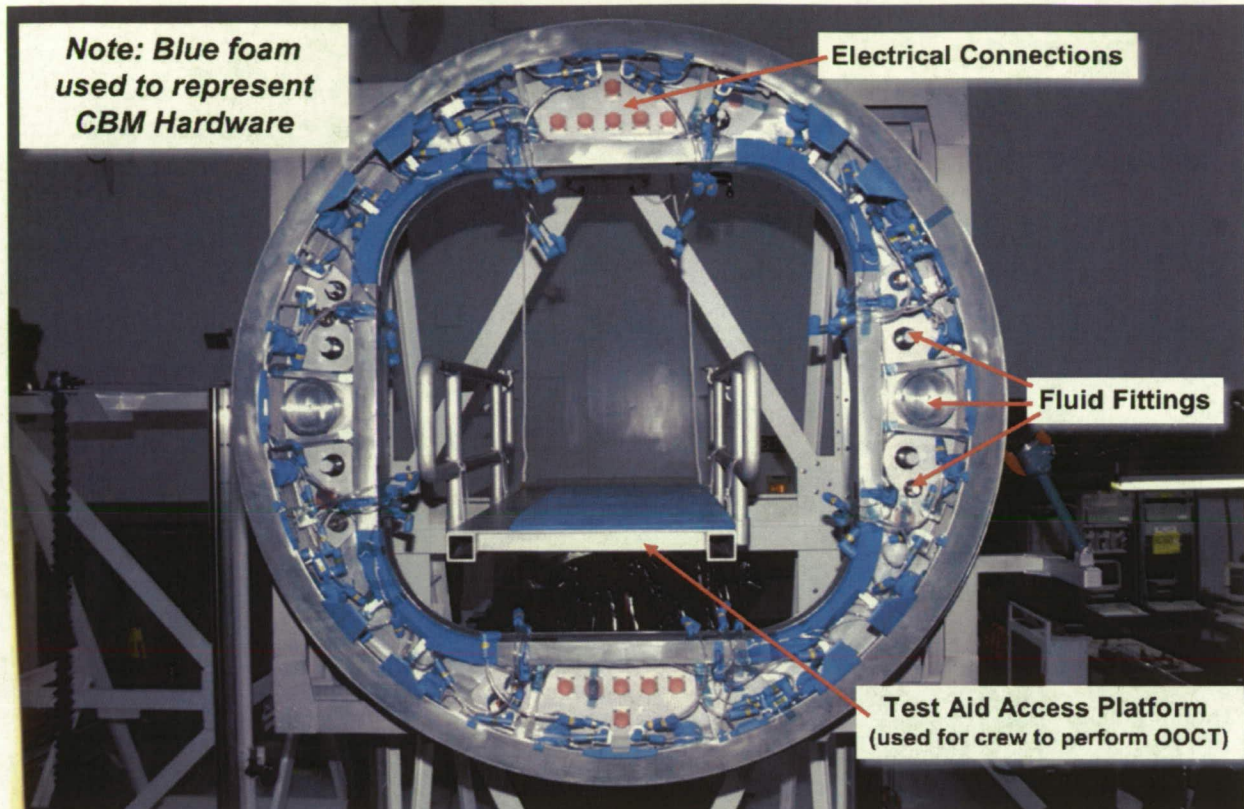


Figure 3 - IVA Test Aid. This Test Aid represented the ISS Node 1 Element and was used to perform an IVA OOC with the flight Airlock.

OOCT's PERFORMED ON ISS

Determining the flight configuration, understanding what flight hardware would be available, designing and building the Test Aid needed, the next step was to bring a number of factors together in an integrated matter to then actually perform a fit check and/or OOC. Ground processing of ISS Elements had begun many years earlier before the OOC concept was created so trying to insert the OOC into an existing schedule that was developed years earlier became one factor that was a serious problem. A main concern regarding the OOC was if it would really simulate a flight configuration. To help alleviate this concern the fit check/OOC would be performed as late as possible during the ground processing flow with the flight hardware in a final flight configuration to minimize any differences between the OOC and how it eventually be configured on-orbit. Once the time period to perform the OOC was established, getting the procedure and flight crew (using an EVA glove for EVA OOC's) together with the flight hardware, test aid and ground processing team was a major integration effort. Everyone involved understood the criticality of the OOC so great strides were made to achieve a successful OOC.

As mentioned earlier, some of the first OOC's planned were between the flight Z1 truss and a Node 1 Test Aid then a Lab Test Aid. Because two different on-orbit configurations were required for the Z1 Truss, two EVA OOC's would be planned. To help consolidate logistics regarding two different configurations, two test aids were built and incorporated into one setup so both OOC's could be performed with one test setup. Figure 4 – Flight Z1 Truss/Node 1 & Z1 Truss/Lab EVA OOC, shows the actual test setup that was used for the OOC's. The photo shown is the 3A mission configuration where the Z1 deployable tray was stowed to allow cable connections between Z1 and Node 1 test aid. The tray they would be lowered to perform the Z1 truss to Lab OOC.

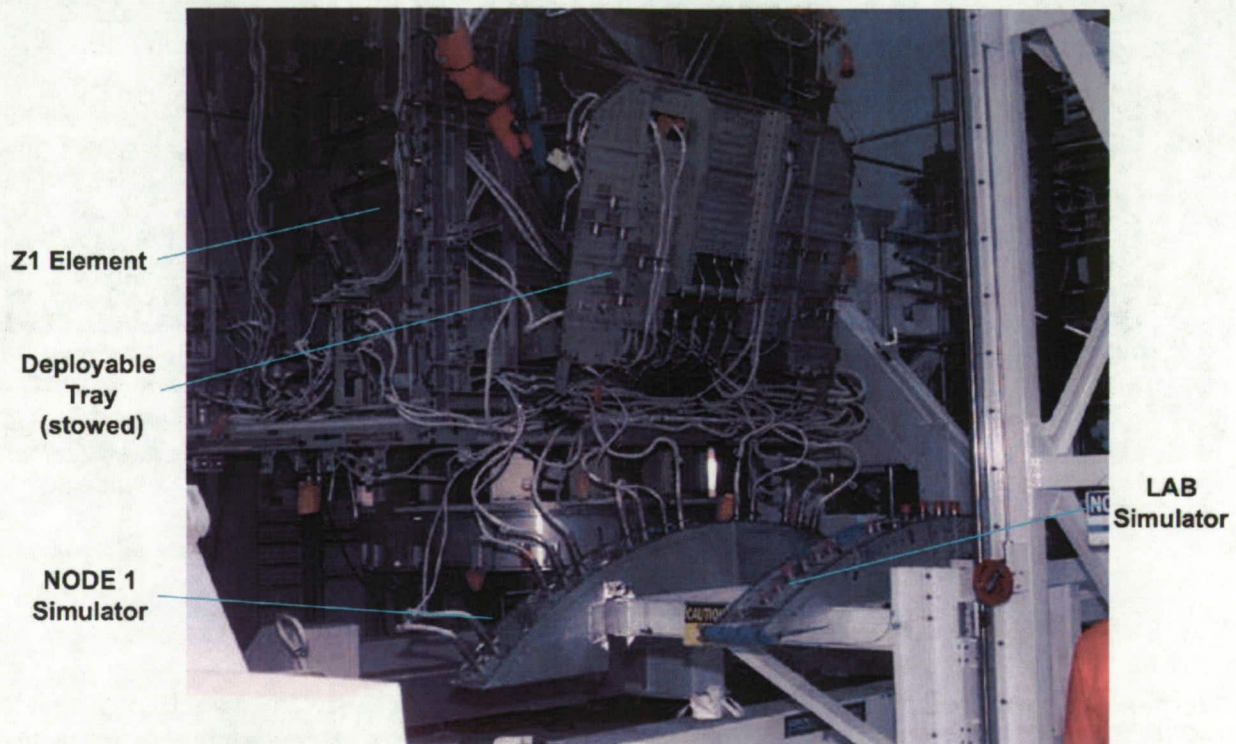
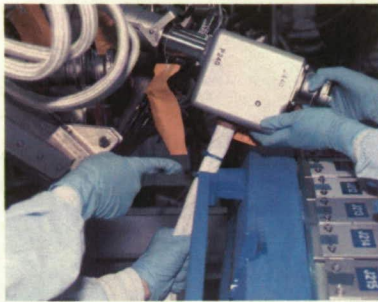
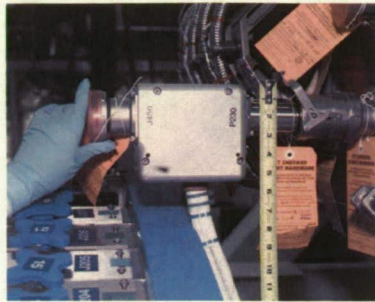


Figure 4 – Flight Z1 Truss/Node 1 & Z1 Truss/Lab EVA OOC

Many problems were uncovered during these EVA OOC's, some of which are shown in Figure 5 - Problems found during Flight Z1 Truss/Node 1 & Z1 Truss/Lab EVA OOC. A number of ideas were generated on how to fix the interferences, which then could be tested on the existing configuration to determine any success. Some of these were to move the connector up one slot, another was to rotate the connector away from the interference. A combination of both was the final solution as shown by Figure 6 – Successful on-orbit mating of Z1 Truss to Node 1. Finding these interferences on the ground made fixes relatively easy as compared to what could have occurred on-orbit if the OOC was not performed. Many EVA OOC's were performed, some containing multiple elements in a very complex configuration as shown in Figure 7 - Node 3, Lab, S0 Truss and Airlock EVA OOC. The EVA OOC's were very important because these represented tasks the crew would perform while in the EVA suit that had a time limit of about 8 hours, so problems discovered and fixed via the EVA OOC's would save precious EVA time.

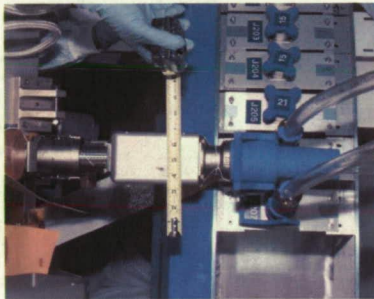


Circuit Interrupt Device (CID) #5
Interferes with handrail

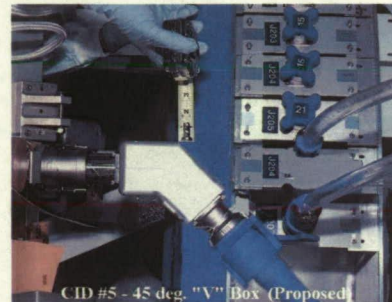


Circuit Interrupt Device (CID) #6
Interferes with hard structure

*Note: Blue foam
used to represent
adjacent flight
hardware*

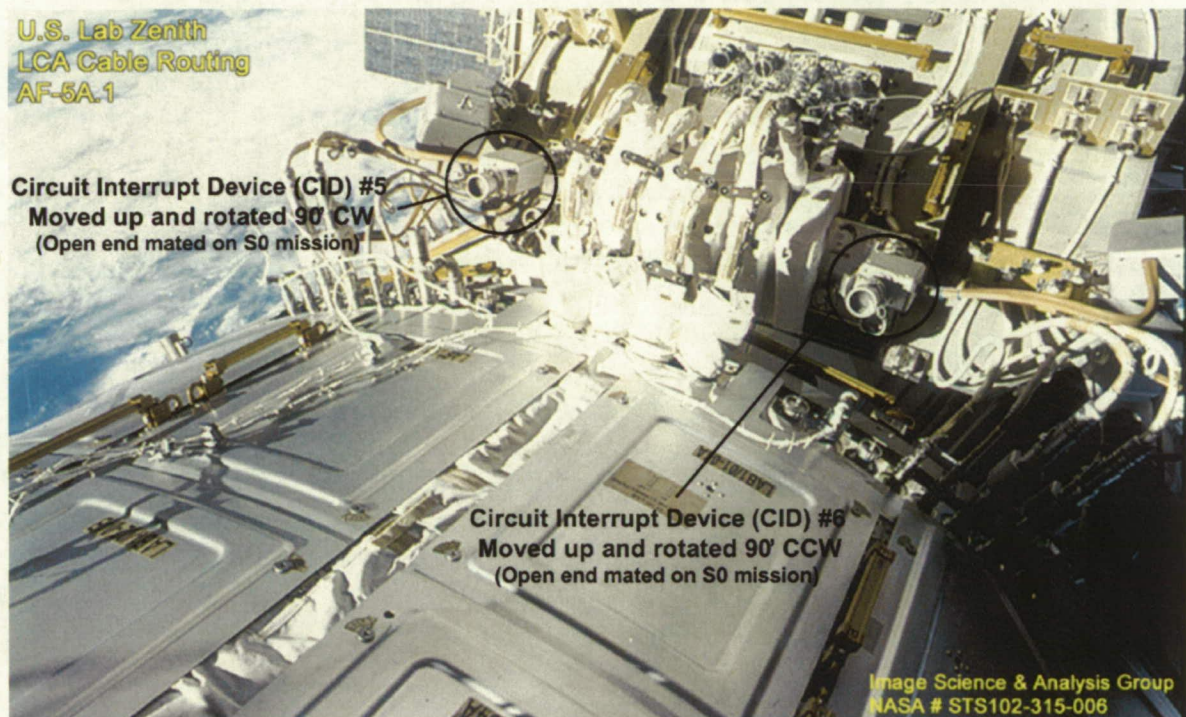


Circuit Interrupt Device (CID) #6
Interferes with connectors



Propose fix, modify Circuit Interrupt Device

Figure 5 - Problems found during Flight Z1 Truss/Node 1 & Z1 Truss/Lab EVA OOST



Note: This location was known as the "Rats Nest" do the fact that umbilical's from Node 1, Z1, Lab and S0 Truss all came together in one congested area.

Figure 6 – Successful on-orbit mating of Z1 Truss to Node 1

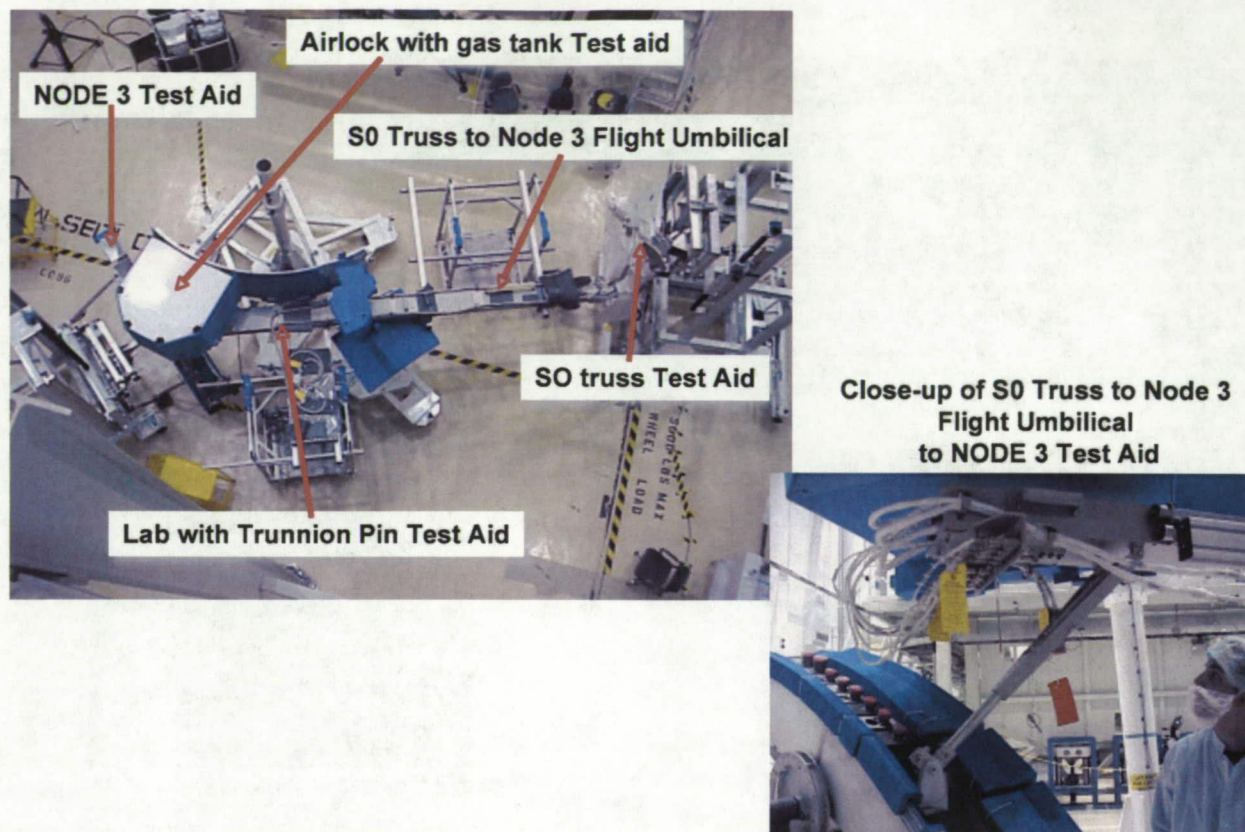
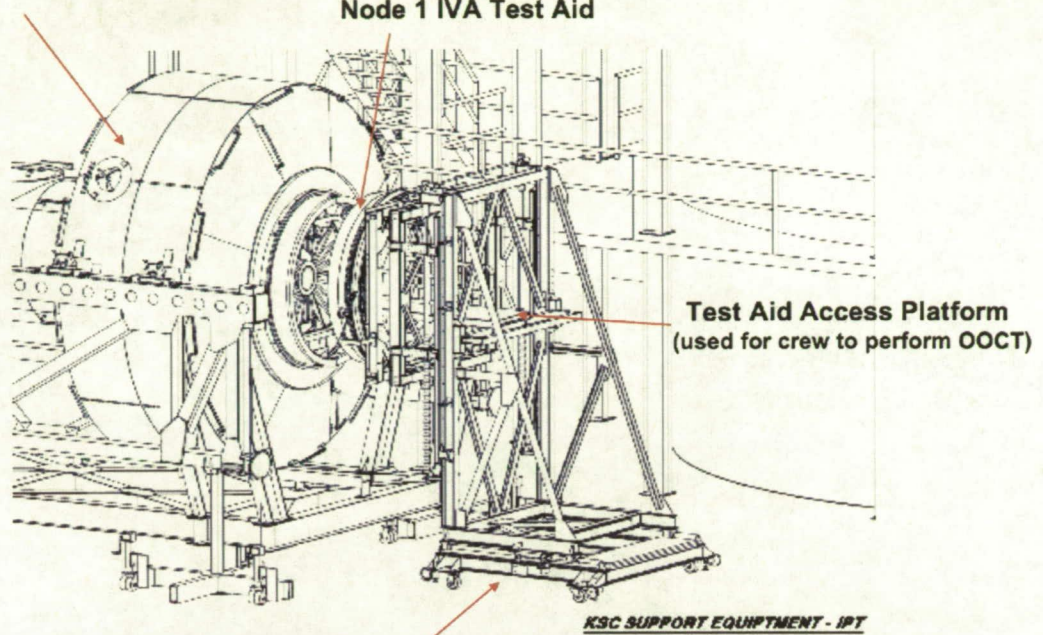


Figure 7 - Node 3, Lab, S0 Truss and Airlock EVA OOC.

The IVA on-orbit operations, while not as time critical as the EVA on-orbit operations, still represented a major step that needed to be accomplished to assure mission success. Many IVA OOC's were performed between the major ISS Pressurized Elements, but in this paper, only the Node 1 Test Aid to Flight Airlock IVA OOC's will be presented. Positioning the IVA Test Aid, shown in Figure 3, into the proper orientation to represent the on-orbit configuration, proved very challenging. Figure 8 – Flight Airlock to Node 1 Test Aid IVA OOC, depicts the configuration of the hardware used to perform the test. Figure 9 – IVA fluid and ventilation jumpers between Flight Airlock and Node 1 Test Aid, shows how the complex criss-cross hardware configuration and the short length of the one jumper that if not found until on-orbit could have been a major setback to Airlock Mission operations. The jumpers were modified and a follow-on IVA OOC was performed to verify the modification fixed the problem. This same scenario occurred during many IVA OOC's where a problem was discovered, the hardware modified and retest performed to verify proper operations. Some of those other problems encountered are shown in Figure 10 – Other IVA problems discovered during IVA OOC's and Figure 11 – Fluid Fitting Torque Device and application to Gamah Fluid Fittings, showing a tool required to torque the Gamah flight fittings on fluid jumpers that routed between ISS Elements.

ISS Airlock Element in GSE stand

Node 1 IVA Test Aid



Test Aid Alignment Fixture

Figure 8 – Flight Airlock to Node 1 Test Aid IVA OOC

NODE 1
Test Aid

IMV Duct

Fluid line
is short

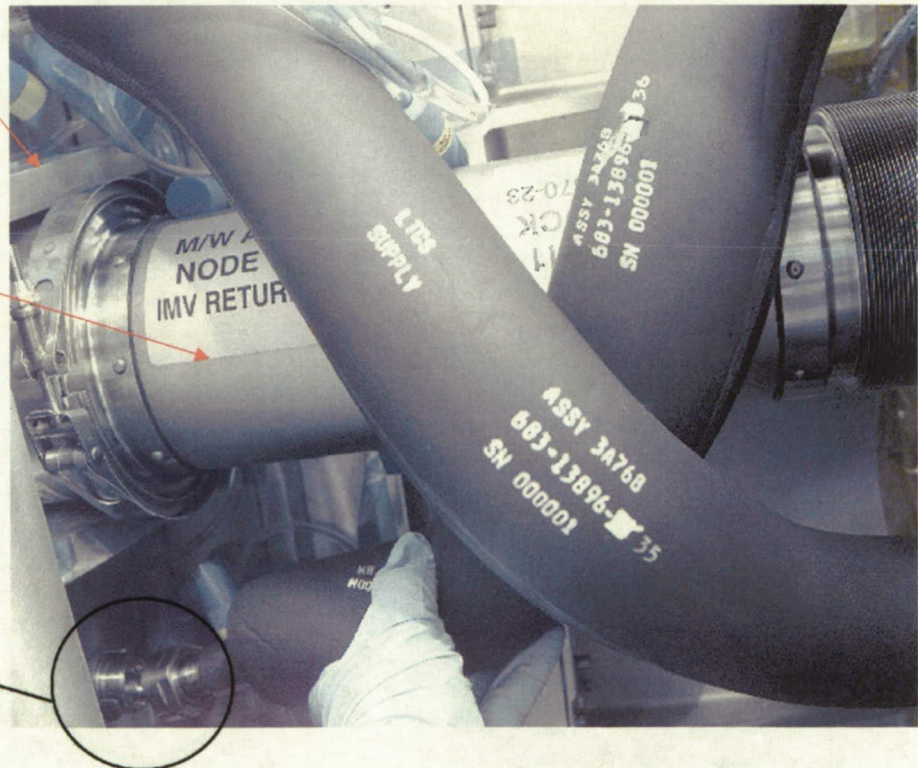
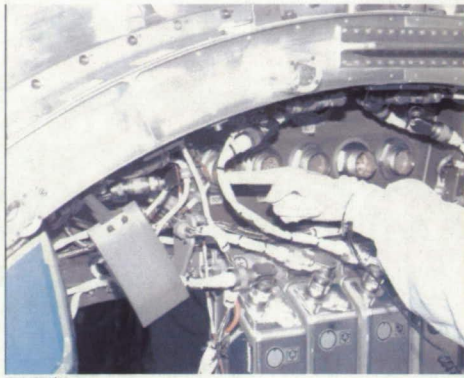
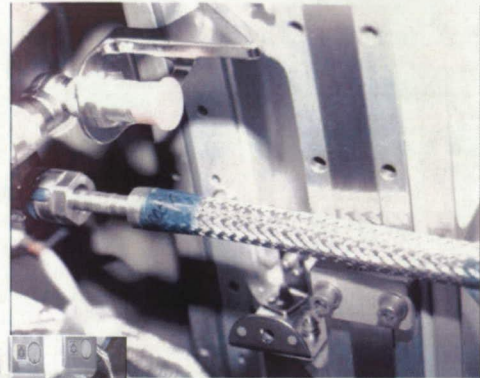


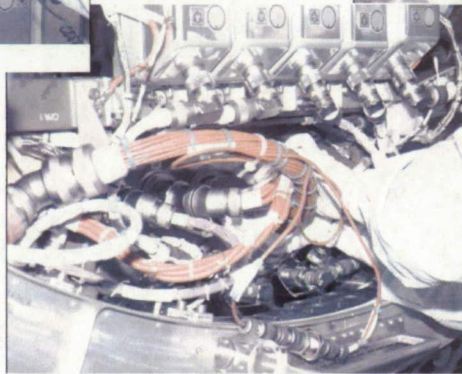
Figure 9 – IVA fluid and ventilation jumpers between Flight Airlock and Node 1 Test Aid



**Jumper interference
with CBM cable**

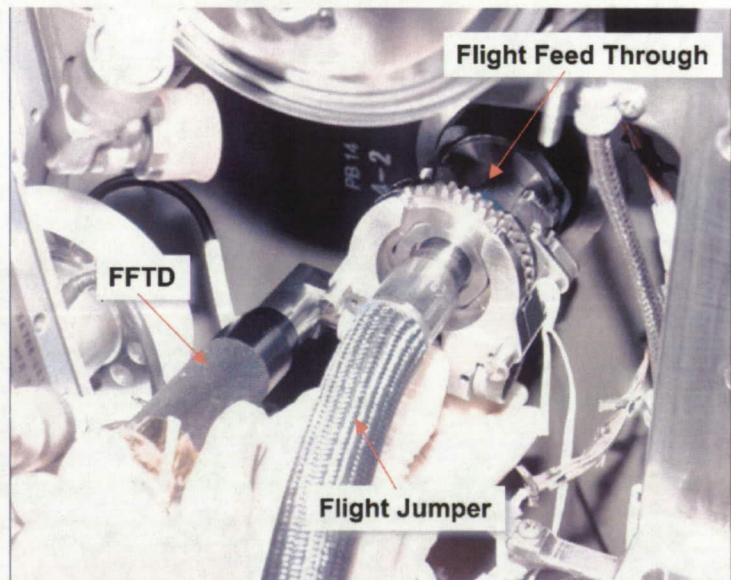
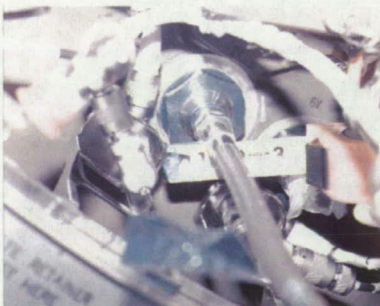


**Jumper interference
with CBM ring**



Hand access problem

Figure 10 – Other IVA problems discovered during IVA OOCT's



**Gamah Fitting required feed through connection to be supported
(to keep from rotating) during fluid jumper torquing**

Figure 11 – Fluid Fitting Torque Device and application to Gamah Fluid Fittings

LESSONS LEARNED

The OOC's were performed on a variety of different hardware for different missions in different configurations that were required to assemble ISS Elements in Earth Orbit. Due to this wide range of applications, many lessons were learned, most of which are documented below:

- Design Flight Hardware and supporting GSE to allow physical mating of flight hardware elements together that are on the ground at the same point in time. By providing clearance on each end of the Element, while in its GSE stand, this could allow both elements to be mated in a flight-to-flight configuration eliminating the need for an OOC for elements that are on the ground together.
- It is critical that the flight hardware is in the final flight configuration. Changes that would occur after the OOC's can cause problems that could have prevented a successful mission.
- Piggyback on MEIT or Integrated Testing. Flight jumpers are used for test, so build test aids to support free end of flight jumpers which would satisfy OOC's. Then connect test GSE cable to the backside of the Test Aid Connectors. Example shown in Figure 13 – Piggyback OOC onto Surface System Integrated Testing.
- ISS Test Aids designed with change out panels. This limits the number of rings built, are easy to reconfigure between OOC's and the panels can be maintained in "flight configuration" for specific missions
- Design, fabricate and assembly test aids in Florida to allow quick turn-around and repair of test aids. Storing the Test Aids near the flight hardware kept the integration of logistics to a minimum while providing the best and quickest support towards the OOC's process.
- Early purchase of flight connectors as well as design and build of flight jumpers is mandatory so future hardware would be ready for near term testing. This was a big problem for ISS where some OOC's had to be performed with connector shells containing no pins due to long lead-time to obtain the flight hardware to configure the hardware properly.
- Flight Crew needs to be involved to get familiar with Flight Hardware and On-Orbit/Surface Operations. Flight Procedures were also verified, modified due to issues discovered during the OOC's and some flight procedures were generated during OOC.
- Work Authorization Document (WAD) should have NASA KSC signature authority and task leader responsibility or designate Local Contractor as task leader. This will take advantage of local flight hardware processing expertise as well as having a task leader who is familiar with KSC ground processing operations.
- Plan early for CxP OOC's and incorporate into Milestone schedules, to allow enough time to obtain hardware required, budget for personnel & equipment, prepare pre-integration tasks and successfully perform the OOC's in the best possible environment.
- Other OOC's lessons learned can be found at the following website location: Public Lessons Learned Entry: 1216, <http://www.nasa.gov/offices/ocel/llis/1216.html>

POSSIBLE APPLICATIONS TO CONSTELLATION PROGRAM

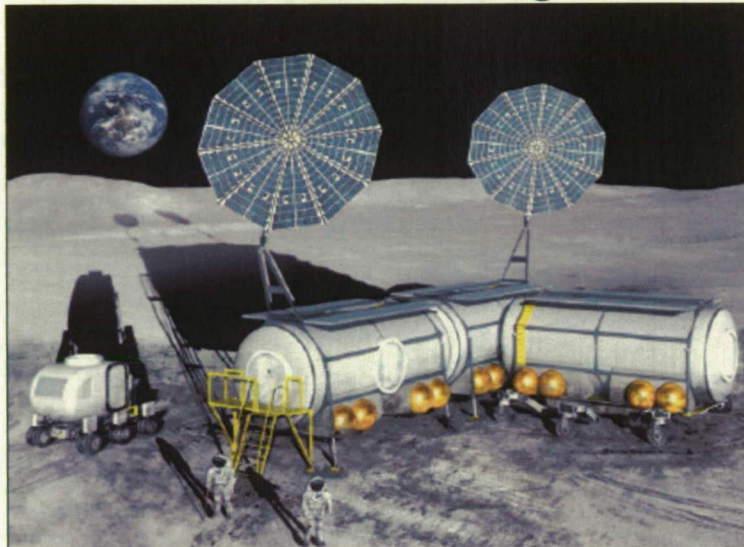
As of the writing of this paper, the Constellation Program Elements are still in the concept/design phase, so now would be the time to begin planning for CxP fit checks and OOC's. Taking the lessons learned from ISS and applying them during these early phases of the Constellation Program will avoid future problems and save money associated with last minute changes or trying to incorporate a new process into a future existing processing flow.

Figure 12 – Possible Constellation Lunar Surface and Lunar Orbit Element, are concepts of what a future Lunar Orbit support system and Lunar Surface System configuration may look like. Assuming these initial concepts of Lunar Surface Systems and Mars Surface System configuration could be, below are a listing of some possible OOC applications for Constellation EVA & IVA operations:

- ISS On-Orbit Operations
 - Orion to ISS Interface
- Earth and Moon On-orbit Operations
 - Orion to Lunar Surface Acquisition Module (LSAM)
 - Hardware in Lunar Orbit
- Surface Operations (Moon & Mars)
 - Surface Habitation Element to Element
 - Surface Extended Surface Element to Surface Carrier Element
 - Surface Rover to Habitation Element
 - Surface Science Packages to Required Interface
 - EVA Suit to Habitation Element
 - EVA Tools

Based on these initial concepts and using lessons learned from ISS, Figure 13 – Piggyback OOC onto Surface System Integrated Testing, shows a possible configuration where a second surface module is being testing against a simulator of the surface element already on the moon. Planning for the GSE to be properly designed to allow an OOC check, the backside of the test aid could be connected to the Surface Simulator, so the OOC is accomplished (a physical check between elements) during setup for the functional test between elements. This same process then could be used for each additional Lunar Surface System Element and Lunar Orbit Elements.

Possible Surface Configuration



Lunar Orbit



Surface Carrier



Figure 12 – Possible Constellation Lunar Surface and Lunar Orbit Element

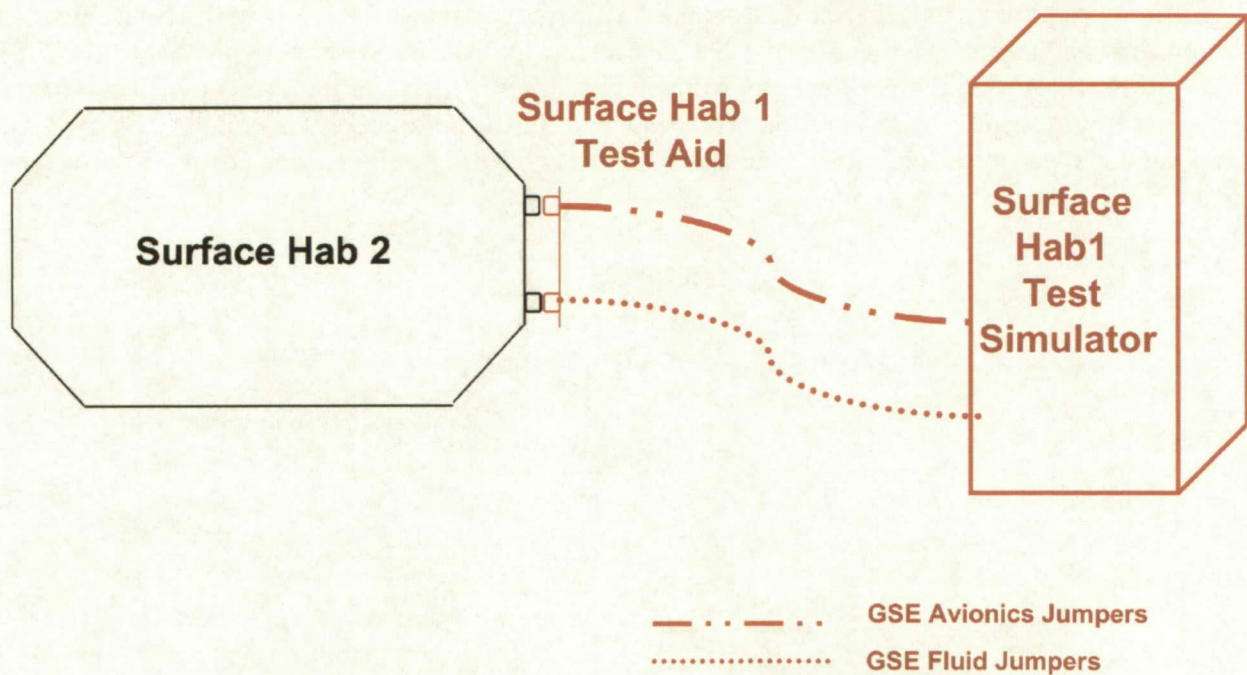


Figure 13 – Piggyback OOC onto Surface System Integrated Testing

CONCLUSION

The OOC concept used during the International Space Station uncovered a wide variety of problems and helped assure on-orbit successful assembly of the ISS Element's. The knowledge gained will very helpful to assuring the same successes for the Constellation Program. Applying the OOC concept to near team Constellation missions should be performed with a long-term goal to continue the OOC concept to Mars Surface Systems and beyond.

BIOGRAPHY

Mr. Haddad holds a Bachelor of Science Degree in Mechanical & Aerospace Engineering and Masters of Science Degree in Industrial Engineering and Management Systems, both from the University of Central Florida. He began working NASA at Kennedy Space Center (KSC) as a mechanical and fluids engineer, assembling, modifying, servicing and testing of flight hardware for domestic and international payloads. He specialized in hypergolic propellants, and was responsible for ground processing flow for Shuttle planetary, observatory and satellite class payloads such as Galileo, Ulysses, Gamma Ray Observatory, TDRS communication satellites and Hubble Space Telescope. Mike performed a six-month detail assignment to Johnson Space Center in Houston, Texas, with responsibilities that included, flight console operations for STS-70 & 71 from the Mission Control Center, working Shuttle/Station upgrade activities and development of Space Station on-orbit operations concepts and requirements. He served as a senior systems engineer working International Space Station (ISS) with primary responsibilities that included Extra Vehicular Activities (EVA) as KSC Point-of-Contact for EVA & Crew Systems responsible for test, verification and on-orbit support of Space Station EVA systems. Mike was also an integration engineer for the ISS Multi-Element Integrated Testing (MEIT) performing requirements generation, test and verification activities. He was in the final selection group for the Astronaut Class of the 1998. Received the NASA Silver Snoopy Award in 2001 for work in EVA operations. Currently Mike is in the KSC Constellation Project Office working Systems Engineering and Integration with responsibilities that include generating Constellation requirements, participation in technical trade studies and KSC Point of Contact for EVA Systems and Lunar Surface Systems.